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BRIEF SUMMARIES OF PAPERS PRESENTED AT THE DGRR SYMPOSIUM ON ELECTRIC SPACE PROPULSION

J. Surugue, et al.

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BRIEF SUMMARIES OF PAPERS PRESENTED AT THE DGRR SYMPOSIUM ON ELECTRIC SPACE PROPULSION

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ABSTRACT

Summaries are presented of papers on the application of fluid magnetodynamics to space propulsion, state of development of the Giessen ion propulsion unit, colloid-particle electrostatic thrusters, diagnostic work concerning ion sources at the DFL, orbital test of an electric propulsion system, the application of primary electric propulsion to space exploration, etc.

Surugue, J. *

Investigations by O.N.E.R.A. On the Application of Fluid Magnetodynamics to Space Propulsion (66-001)

The research done by O.N.E.R.A. in the area of electric propulsion encompasses experiments with electrothermal, plasma and ion propulsion units.

In the first case, our efforts are primarily concerned with the investigation of fundamental stability ignition phenomena, as well as with a comparison of the experimental outputs and the theoretical values calculated beforehand.

The guide rail plasma accelerator is investigated using measuring devices; the development work of plasma accelerators primarily extends to the changing field accelerator, for which theoretical and practical experiments are carried out.

At the present time, we are investigating mercury ion accelerators as an example of an electrostatic accelerator. The investigations will also be extended to heavy organic ion accelerators.

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Sprengel, U. *

Calorimetric Temperature Measurements of a Nitrogen Plasma Beam (66-002)

In order to determine average temperatures in ionized gas flows, primarily spectroscopic methods have been used up to the present. However, it was practically impossible to determine local temperatures or temperature gradients. In many cases, the measurement accuracy obtained was not sufficient. On the other hand, J. Grey (Princeton University, U.S.A.) has developed a calorimetric probe method for the determination of local temperatures and temperature gradients, which has performed well in the measurement of local temperatures up to about 15,000°K in atmospheric argon subsonic flows. In addition, this method makes it possible to determine the stagnation pressure and therefore the flow velocity. In preliminary experiments for the determination of these local state quantities in the plasma beam of the continuous electromagnetic propulsion unit Keman, we investigated the suitability of the probe method of Grey using a commercial plasma burner. This was carried out at atmospheric pressure and at a pressure of 8.5 Torr. The working gas was nitrogen, and we assumed thermodynamic equilibrium.

The details of the measuring principle, the experimental procedure and the experimental results are described.

Löb, H. **

State of Development of the Giessen Ion Propulsion Unit (66-003)

The design of measurements for a mercury ion propulsion unit, developed at the 1st Physical Institute at Giessen, were described at the Joint Yearly Meeting of the DGRR and the WGLR held in Berlin, September 14-18, 1964. It is an electrostatic propulsion unit, and the fuel is ionized in a high frequency ion source. In the meantime, further investigations have been carried out. Several important improvements were made. Thus, the thrust was increased 2½ times. The energy efficiency and mass efficiency were improved. This was carried out by the optimization of the extraction system, the use of weak permanent magnets (field strength 10 oersted), reduction of the ion source pressure by one order of magnitude and transistorization of the high frequency transmitter, etc. The present propulsion unit parameter

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units are (as of October 15,1965): Thrust 0.5p, weight of the propulsion unit 1.5 kg, energy efficiency 80%,, mass efficiency 90%, power input 470 W, specific impulse 12,000 sec.

The lecture will show details of construction as well as the propulsion unit parameters as a function of the operational parameters.

Mickelsen, W. R. *

Colloid-Particle Electrostatic Thrusters (66-004)

Cislunar missions are investigated from the point of view of the requirements for an electric propulsion unit. It is shown that the exit velocity must be on the order of 10,000 to 40,000 m/s, for optimum performance of vehicles equipped with electric propulsion and carrying payloads to the Moon. This is also the region of exit velocity in which present electric propulsion units show a small degree of performance. A short summary of the experimental performance data of these propulsion units underlines this fact. An electrostatic propulsion unit containing colloid ion sources promises a high efficiency in the region of exit velocities mentioned above. The theory of operation, the construction and the various types of these propulsion units are described in detail.

Most of this paper is concerned with a summary of the research and development, progress and plans concerning electrostatic propulsion units with colloid ion sources. If an acceleration voltage of 100 kV is used, then the particles must have 10,000 to 100,000 amu † elementary charges, in order to allow operation at exit velocities between 10,000 and 40,000 m/s. It is shown that the spectrum of the quotient of amu/q must be very narrow in order that the efficiency of the propulsion unit may be appropriately enlarged. The search for methods of fabrication of colloid particles and the charging of them is presently the most difficult problem in present day research on electrostatic propulsion units with colloid ion sources.

Particles with 100,000 amu/q have been fabricated by homogeneous formation of crystallization kernels. Methods of electron attachment and electron bombardment for the purposes of particle charges have

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† amu = atomic mass unit.

been investigated. One important question, which must be answered for this type of propulsion, is whether all of the fuel vapor can be transformed into colloid particles. New data concerning the mass efficiency are given.

The method of spraying fluids from hollow needles resulted in charged drops of 12,000 amu/q. The development of a propulsion unit with electrostatic spraying has begun. New measurement values relating to the suppression of the polymer ion pulling current are given. Colloid sources of this type have resulted in an amu/q spectrum with a propulsion efficiency of 75%.

Several other designs of propulsion units with colloid ion sources are described and their state of development is discussed. The prospects for electrostatic propulsion units with colloid ion sources are discussed and are considered to be very good.

Bahr, A.*, Baumgarth, S. *, Bessling, H.**

Diagnostic Work Concerning Ion Sources at the DFL (66-005)

Two types of ion propulsion are being investigated at the German Research Institute for Air and Space Travel in Braunschweig:

1. Propulsion with Gas Discharge-Ion Source

2. Propulsion with Contact-Ion Source.

We are attempting to compare the overall efficiency and the lifetime of a gas discharge ion source with that of a contact ion source. For this purpose, we first developed measurement apparatus for the determination of the parameters of an ion beam of a duoplasmatron. Since the ion beams required for the experiment and corresponding to various adjustable current intensities and current densities depend on the settings of the duoplasmatron, we first discussed the mechanism and the mode of operation of the duoplasmatron.

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The function of the duoplasmatron is determined by a number of parameters: the emission intensity of the oxide cathode as a function of the heating power, the light arc current, the magnetic field strength in the pole shoe lens as a function of the coil current, the potential of the intermediate electrode, the acceleration voltage and the geometry of the system. The method and devices for the measurement of parameters in the ion beam are described. When the ion current intensity is measured with the aid of a cage, it is important to prevent the exit of secondary electrons. The determination of the beam power is carried out by leading away the heat created by the impact of ions, by means of a cooling system and by measuring the input and output temperatures and the coolant throughout. In order to determine the divergence, the ion beam is made visible within a plane of interest by means of an ion converter, the construction and principle of which are shown. The number of elementary charges per ion in the beam can be determined by means of a deflection system of electric and magnetic fields, according to the principle of the Aston mass spectrograph. The determination of the particle velocities was carried out by means of an apparatus which contained an electric and magnetic field which deflected the beam. The intensity of the electric field can be adjusted in such a way that the deflecting forces compensate for each other. The velocity can be calculated from the value of this field intensity. This method was already used by J. J. Thomson for determining particle velocities in atomic physics.

Contact ionization is discussed in detail and the principle is outlined. The experimental apparatus required for the investigations is discussed in detail. The following quantities are to be optimized for the electrostatic ion propulsion unit: ion current density, thrust, total efficiency and lifetime. The dependence of the ion current density on porosity of the emitter are first investigated as a function of temperature and pulling voltage. For this purpose it was necessary to carry out porosity measurements using a mercury porosimeter before the tungsten emitter could be welded into the frames. The course of the pore radius distribution of an emitter is shown. A measurement of the ion current with an emitter having 40% porosity is described.

Davis, J.*

Orbital Test of an Electric Propulsion System (66-006)

This article describes electrostatic ion propulsion with a contact ion source, fuel reserve container and fuel reserve feed system. The author also discusses the adjustment of the electrical output and the control which was required for the complete electrical propulsion system which was placed into orbit in April, 1965, for experimental purposes.

The questions regarding design due to radiation hardness are discussed. The development and experimental programs are described.

The author has been program manager for the orbital experimental program for four years.

Stearns, J. W.**

Factors Determining the Applications of Primary Electric Propulsion to Space Exploration (66-007)

A. Fundamental Technological Factors

The requirements for electrical auxiliary and primary propulsion units are discussed, and the present technological state of the are is given for electrical primary propulsion units, propulsion unit elements and auxiliary systems. When plans are made for the use of electrical propulsion units in space flight missions, the "requirements versus availability" factor is to be considered as the principal problem. Our chemical propulsion systems are continuously being developed and represent a standard with which all kinds of advance propulsion units must be compared. Therefore, the achievable performance of chemical propulsion units is discussed and the nature of the limitations inherent to them are carefully defined. Increased requirements in mission energy has a direct effect on the starting weight of the rocket, on the general complexity and costs. Electrical propulsion units must be able

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to compete with respect to costs and reliability over the mission. They must also compete in performance and must guarantee the realization of the mission goal. The principal problems for electrical propulsion systems are defined. Nuclear electric, as well as solar electric, energy systems for electrical primary propulsion units are described in general. Recent studies at the Jet Propulsion Laboratory are described.

B. Mission Factors

The requirements for missions which influence the application of electrical propulsion units are exceptionally complicated and require an extremely wide parametric mission analysis. Several results of mission analysis are summarized and illustrate one of the factors upon which the applications depend. Four elements of the mission analysis are described in detail, and the potential importance of the electrical propulsion unit for extended space missions is demonstrated.

1. The adaptation problem of the electrical propulsion unit and the energy supply unit is investigated with regard to the choice of space missions.

2. The availability of the principal energy unit and its influence on the mission are analyzed.

3. The availability of propulsion systems, the analysis of the mode of thrust generation and its influence on the mission are treated individually.

4. The requirements for the size and mass of the starting vehicle are shown for various missions.

C. Construction Factors for Space Vehicles

Theoretical planning studies of electrically propelled space vehicles which have been carried out over the last few years are summarized. These studies have sufficient depth so that a definition of the principal limitations in the construction of space vehicles for planetary missions can be seen. Primary energy units, either nuclear electrical or solar electrical ones, are an important element of the space vehicle. Space vehicle dynamics, thermal and nuclear radiations, electromagnetic fields, navigation and control interactions are discussed. The imminent availability of light solar energy units as primary sources and their application in the construction of space vehicles is discussed.

Other important features of space vehicles include questions such as thrust angle, jet divergence problems, electromagnetic interaction,

fuel used and thermal design.

Lindner, F.,* Wichmann, H. G.**

Investigations of the Principle of Hall Current Accelerators (66-008)

Recently, the Hall current accelerators have gained an importance among the electrical propulsion units. Hall currents can occur in the motion of current carriers through non-parallel electrical and magnetic fields, when certain criteria are satisfied. Due to the interaction of H all currents with the magnetic field, forces are generated which lead to an acceleration of the plasma.

The principle is applied for the subsequent acceleration of the plasma for arç propulsion units or also for the electrical acceleration of ions within a quasi-neutral plasma.

Various concepts having specific advantages and disadvantages result. During the investigation of the criteria for the usefulness of the accelerators, we have considered the favorable operational conditions as well as the loss mechanisms in the case of space missions.

Schreitmüller, K.***

Plasma Source for Hall Accelerator (66-009)

A low voltage arc is used to generate a plasma which is as highly ionized as possible. The arc burns in a capillary made from ceramic material. The degree of ionization and the effectivity, that is, the ratio of the ion current to the total current, are especially interesting. The dependence of these quantities on the dimensions of the capillary, the gas pressure and the flux are discussed and are compared with

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measurements. Furthermore, the influence of a longitudinal magnetic field on the operational behavior of the capillary arc is investigated.

Au, G. F.*

Report on the First Experiments with the Electromagnetic Accelerator KEMAN (66-010)

There are two fundamental methods of increasing the exit velocity of a plasma:

1. The plasma current can be made so large that an additional acceleration occurs due to the eigen magnetic field of the plasma itself.

2. By applying external electrical and magnetic fields.

In addition to the $\vec{j} \times \vec{b}$ -- or crossed field accelerators -- the Hall current accelerators have become important during the last few years.

The experimental apparatus KEMAN has a coaxial arrangement of the cathode and the anode and an external magnetic field which is primarily directed in the axial direction. The device has the advantage that the generation and acceleration of the plasma is carried out in a compact unit.

We first carried out investigations on the ignition and stability of the light arc plasma. We found a very good ignition capability of the arc for gas pressures between 0.5 and 3 Torr. Initial light arc instabilities were removed by means of systematic variations, especially variations of the shape of the cathode. We obtained information for the geometric design of the cathode using high-speed photography. In addition, we primarily measured the current-voltage characteristic of the light arc as a function of the axial magnetic field gradient for plasma pressures between 0.5 to 5 Torr.

Color photographs of the accelerated plasma beam lead one to

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conclude that a separation of the charge carriers of both signs is possible.

The experiments presently underway and in preparation are designed to explain the acceleration mechanism which has remained unknown up to the present.

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